

# Knowledge Aided SAR Target Detection and Display Remap

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- **RESULTS TO DATE**

- CFAR STUDY
- IMAGE REMAPPING

- **FUTURE PLANS**

- REMOVING BLOWING TREE SMEARS
- FOCUSING TARGET SMEARS MOVING ON KNOWN ROADS
- GMTI CHANGE DETECTION

- **CONCLUSIONS**

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- **CONCLUSIONS**

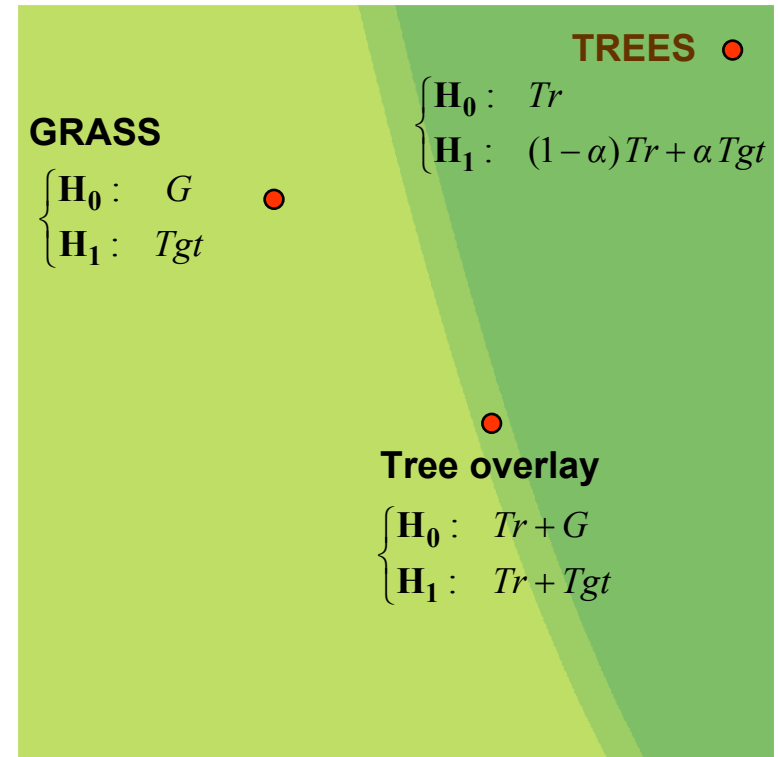
- **PROBLEM:** CFAR Algorithm performs poorly around the clutter boundaries, because Background Statistics are inaccurately estimated, thus violating the background homogeneity assumption.
- **SOLUTION:** KASSPER allows the segmentation of the scene to different clutter classes, and the modeling of the tree overlay regions.
- **Knowledge Source:** DFAD, DTED, Previously Collected SAR.

## ● ISSUES

- **SEGMENTATION:** The quality of the segmentation, hence the computed statistics, depends on the accuracy of the knowledge.
  - What is the sensitivity of the KASSPER CFAR to that accuracy?
- **TRAINING:** Computation of the statistics of a segmented scene must be achieved by avoiding possible targets in the scene or different types of clutter.

**Objective:** To illustrate CFAR performance improvement gained by *a priori* knowledge of the clutter boundary, using simulated SAR scenes

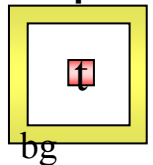
- 200 simulated scenes are generated by complex Gaussian distribution
- Each scene consists of an area covered by grass only, tree only, and both.
- The relative RCS of the tree was set to be 5 dB higher than that of the grass.
- Targets along the boundaries, on grass side and in the overlay region, were inserted at different locations around the overlay boundary
- Target RCS was set at 10 dB higher than tree RCS.



**CFAR Decision Statistic**

$$\delta(X) = \begin{cases} 1 & \text{if } \frac{\sum_{k=1}^n |X_k|_t^2}{\sum_{k=1}^m |X_k|_{bg}^2} \geq \tau \\ 0 & \text{otherwise} \end{cases}$$

**CFAR Template**

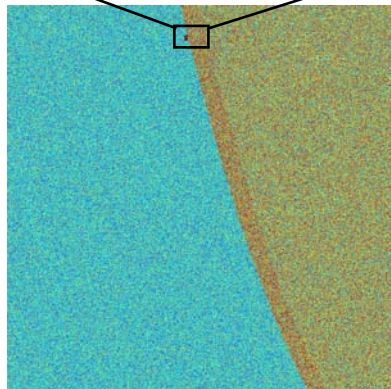
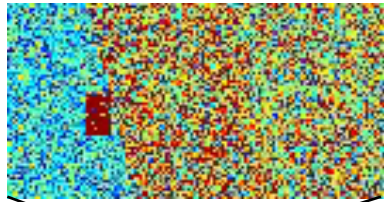


# CFAR Experiment Targets on Grass Close to the Overlay

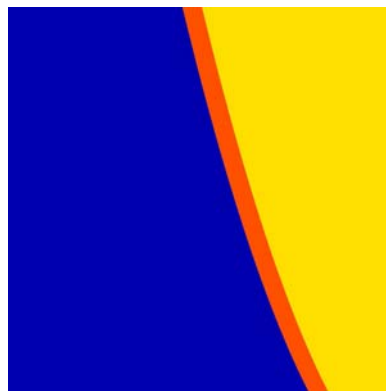
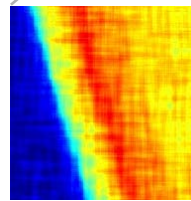
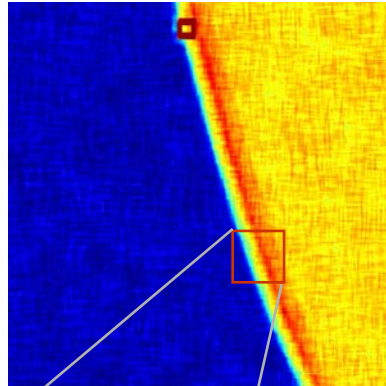
CFAR Target Mask = 1 pixel

CFAR background  
variance

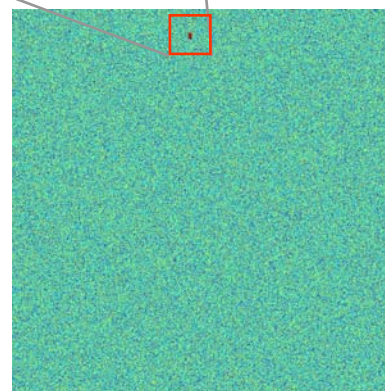
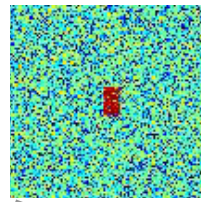
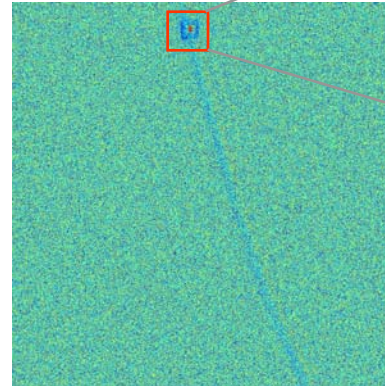
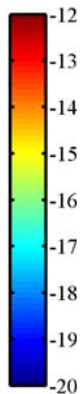
CFAR Detection  
Statistic



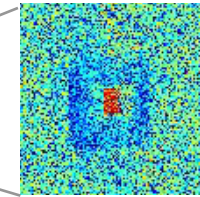
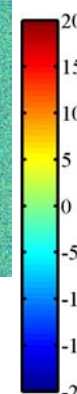
Sample of  
Simulated Image



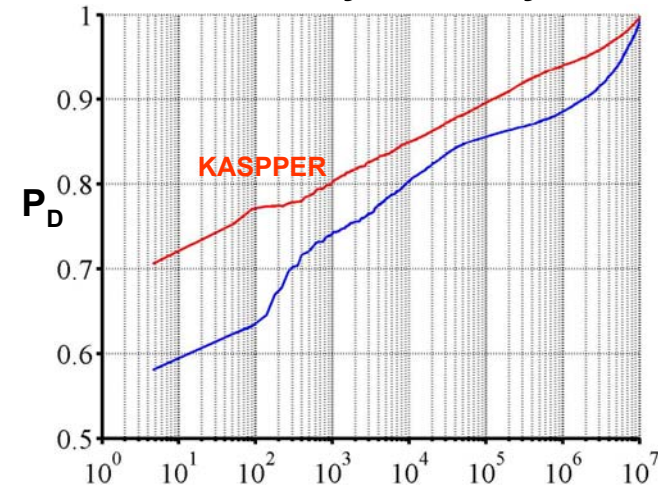
KASSPER CFAR  
background variance



KASSPER CFAR  
Detection Statistic



ROC for grass region close to  
the overlay boundary



False alarms per km<sup>2</sup>

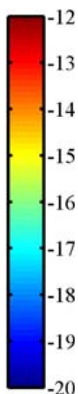
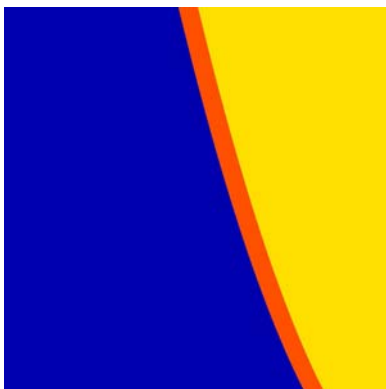
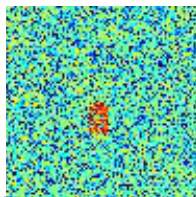
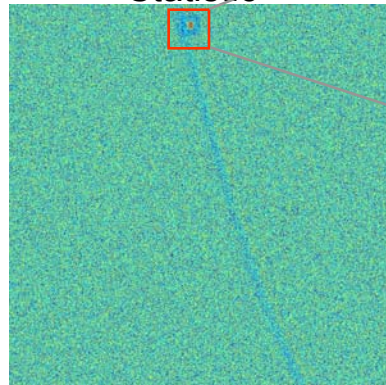
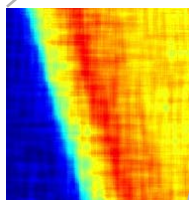
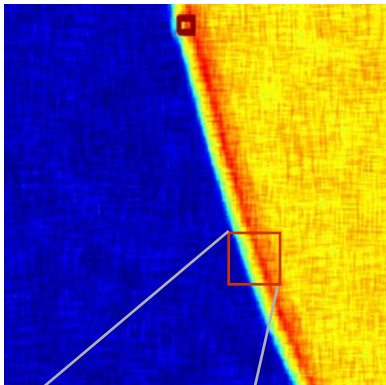
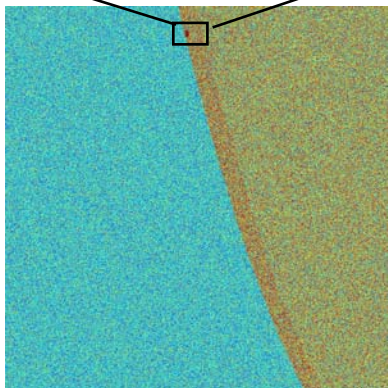
The ROC curve illustrates  
an order of magnitude  
reduction in the number of  
false alarms at  $P_D = 0.8$  if  
accurate knowledge is  
used in KASSPER CFAR.



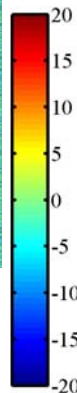
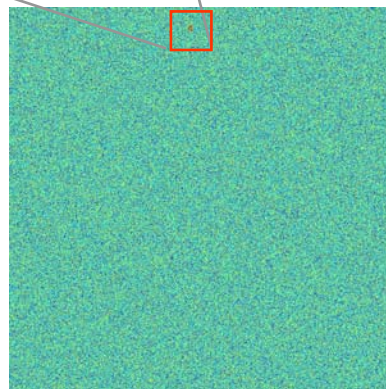
CFAR Target Mask = 1 pixel

CFAR background  
variance

CFAR Detection  
Statistic

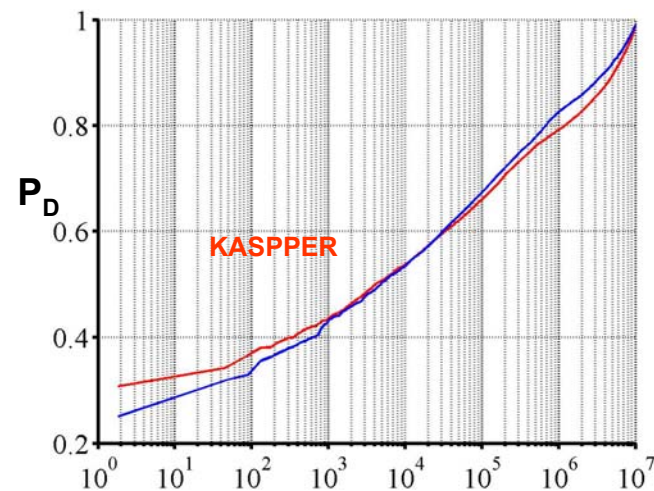


KASSPER CFAR  
background variance



KASSPER CFAR  
Detection Statistic

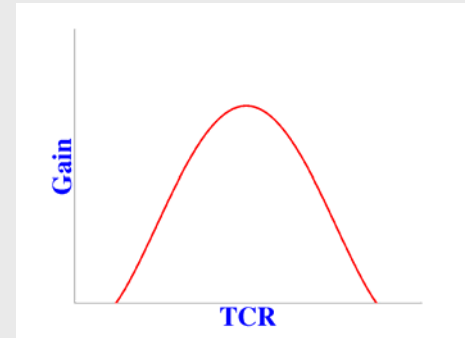
ROC for Overlay Region



False alarms per km<sup>2</sup>

The ROC curve illustrates  
no relative change in  
performance even if the  
knowledge is very  
accurate.

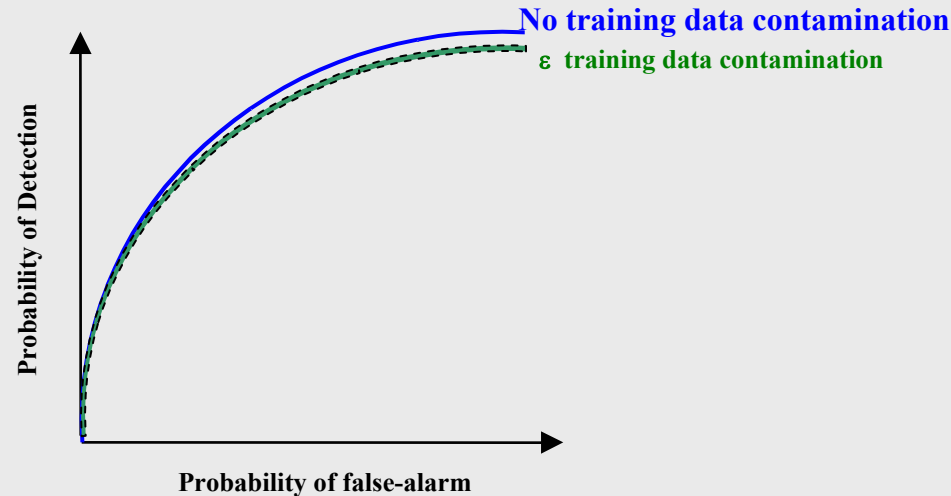
- KA-CFAR has relatively
  - low gain at either high TCR or low TCR
  - High gain at moderate TCR





- Segmentation and Training

- **TRAINING:** Computation of the statistics of a segmented scene must be achieved by avoiding possible targets in the scene or different types of clutter. As a result of inaccurate knowledge
  - Perturbation analysis shows that the ROC curve moves down, implying more FA at a fixed  $P_D$



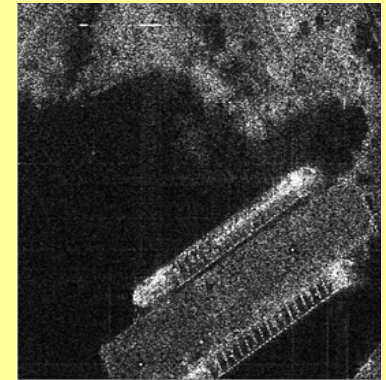
- **SEGMENTATION:** The quality of the segmentation, hence the computed statistics, depends on the accuracy of the knowledge.
  - OPEN ISSUE

- **Problem:** As more operational SAR sensors are deployed and the number of experienced image analysts decreases, the need for effective SAR image quality enhancement becomes increasingly important.
- **Solution:** Intelligent segmentation and remapping of the image using DFAD/DTED information to separate uniform clutter, cultural clutter, etc., may be used in a variety of applications.
- **Knowledge Source:** DFAD/DTED

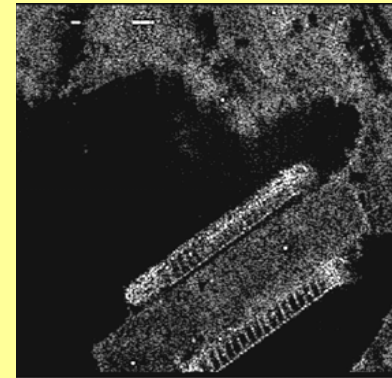
## Super SVA vs. its segmented variety



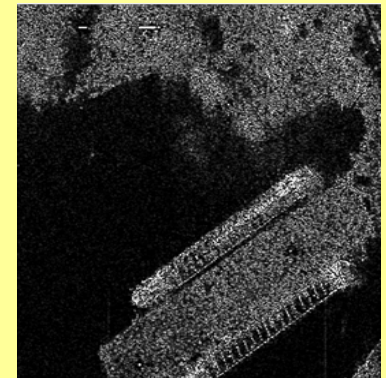
Baseline image



Super SVA



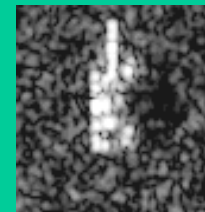
Segmented SVA



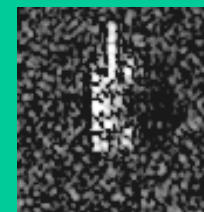
Segmented Super SVA

## Relative Quality and computational complexity of a few super resolution techniques.

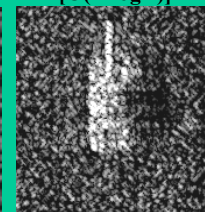
Baseline



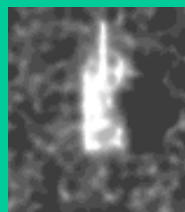
SVA [ $O(N)$ ]



Super SVA  
[ $O(N \log N)$ ]

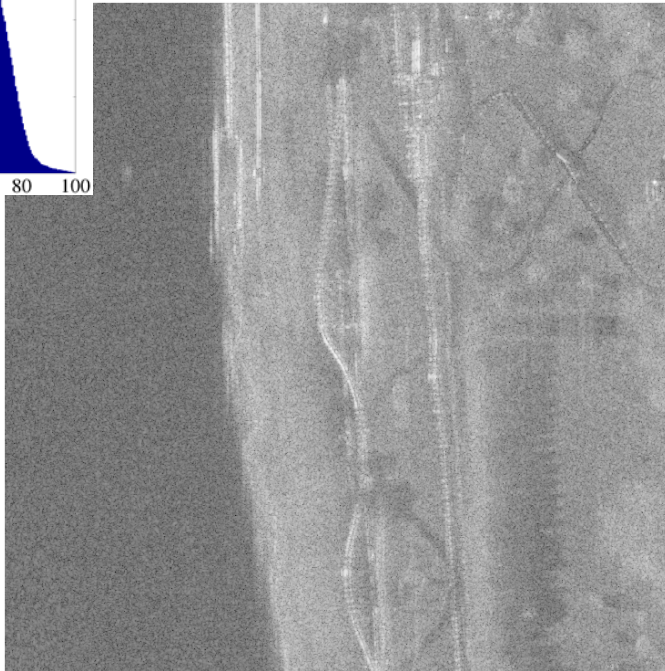
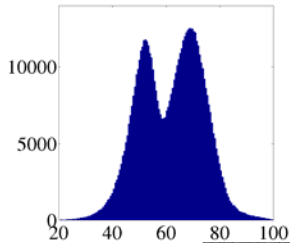


MVM [ $O(N^3)$ ]



- SAR scenes typically have a **70dB** dynamic range
- Challenge
  - The display media (e.g. monitors) have **30 dB** dynamic range
  - The print media have as low as **10 dB** dynamic range
- Image assessment by IAs demands an interpretable and rapid display of SAR imagery
  - This requires an algorithm which remaps a 70 dB to a 30 dB dynamic range
  - Or equivalently, from **16-bit gray-scale** requirement to **8-bit**

## LOG Magnitude scaling



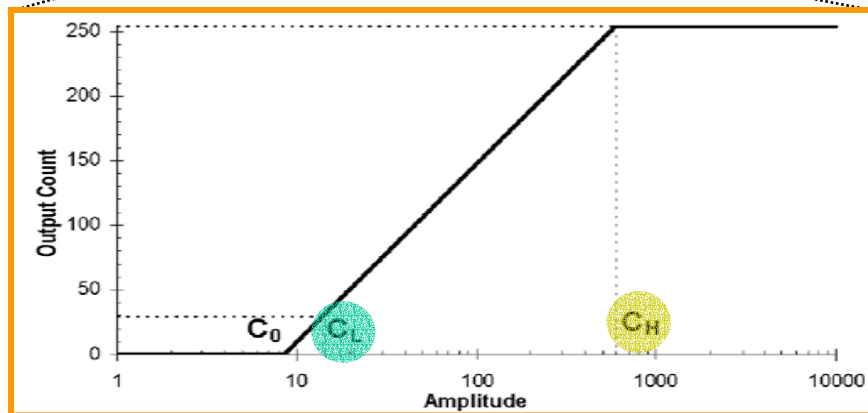
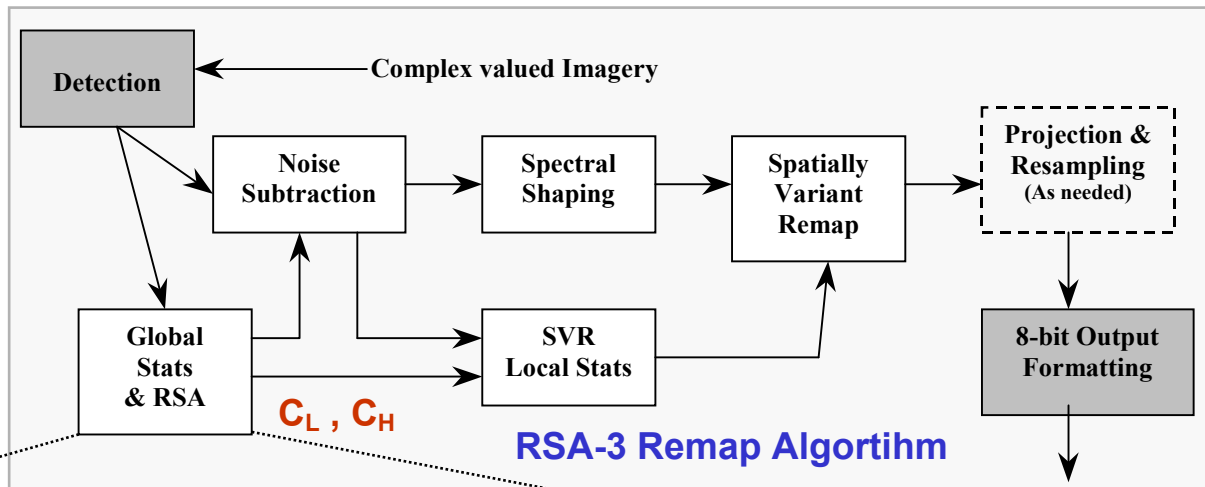
Typical log-magnitude SAR Image  
(Boblo Island, Detroit)

## Remapped by RSA-3

CL = 6.6 , CH = 2076.0



- Remap Selection Algorithm (RSA-3) was developed at Veridian.
  - $C_L$  and  $C_H$  are first calculated from global statistics.
  - Noise subtraction and spectral shaping may further enhance the image quality of the remapped image.



GLOBAL Power-law Remap Function

RSA-3:  $\mathbb{R} \rightarrow [0,255]$

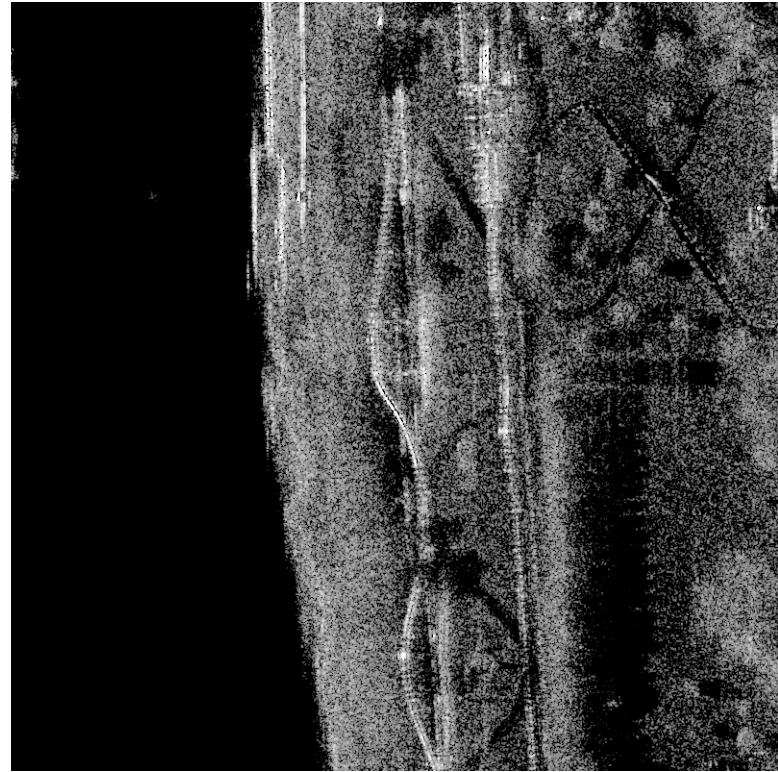
- **Problem:** For SAR imagery with significant low return areas (water, paved roads, shadows, etc.) the quality of the Remap algorithm product (e.g. RSA-3's) degrades significantly.
  - **Solution:** Creating a **mask** for the (predicted) low return areas using SAR Maps, DFAD and DTED would allow more appropriate calculation of the important  $C_L$  and  $C_H$  by RSA-3.
  - **Knowledge Source:** **Coarse** DFAD, DTED, SAR Map
- 
- **NON-KASSPER Solution:** Veridian has been working on RSA-4 remap algorithm which produces the mask automatically from the statistics of the scene.



**Unmasked:** CL = 6.6 , CH = 2076.0



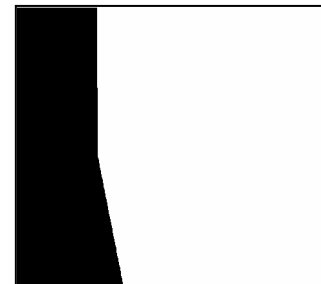
**Masked:** CL = 10.3 , CH = 1067.8



Noticeable improvement in image interpretability  
is achieved by using the KASSPER Mask

Image: Boblo Island Amusement Park, Detroit

**KASSPER mask**



## RSA-3 outputs on A Sub-Image Containing Various Percentage of Low Return Area

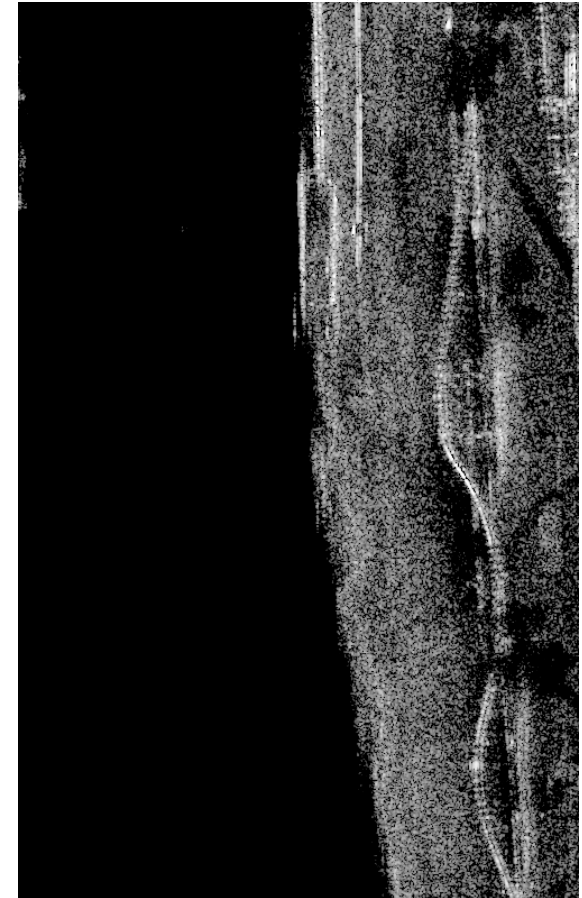
**Unmasked:** CL = 11.2 , CH = 943.8    **Unmasked:** CL = 1.5 , CH = 106840.8    **Masked:** CL = 10.2 , CH = 1183.7



**Unmasked** RSA-3 Image quality is high for no or small areas of low returns



**Unmasked** RSA-3 Image quality diminishes as the low return areas occupy more of the image.

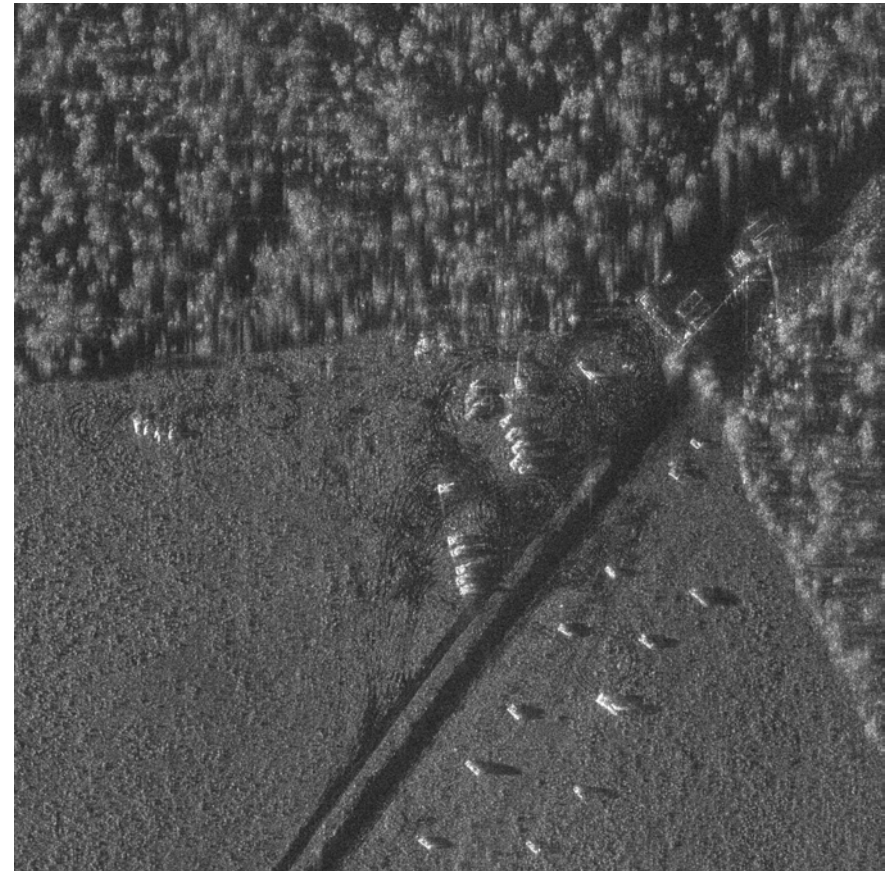


**Masked** RSA-3 Image quality remains invariant.

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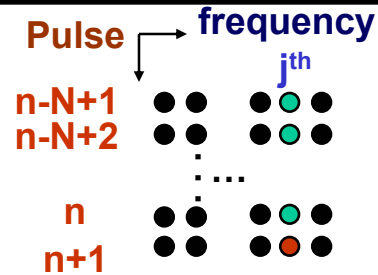


- **Problem:** For long integration time, the streaks caused by blowing trees may obscure targets in the open.
- **Solutions:**
  - Auto-focusing of the treed areas provided by DFAD
  - Prediction-based filtering using the knowledge of the treed areas
- **Knowledge Source:** DFAD

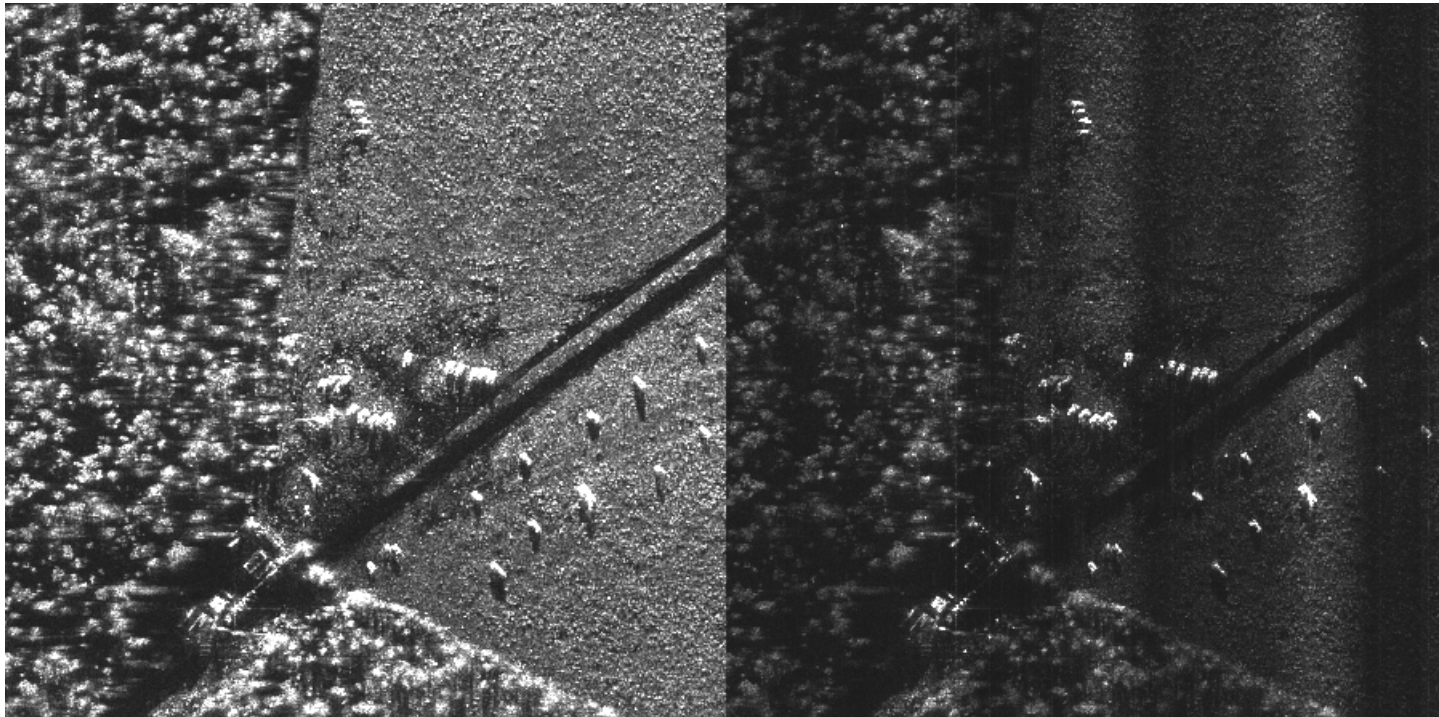


- Given that
  - Moving clutter returns are uncorrelated from pulse-to-pulse
  - Target returns are correlated over a number of adjacent pulses

One can predict the target signatures in homogeneous white clutter (KASSPER).



$$\min_{w_k} E \left( \left| s_{n+1,j} - \sum_{k=0}^{N-1} w_k s_{n-k,j} \right|^2 \right)$$



Original

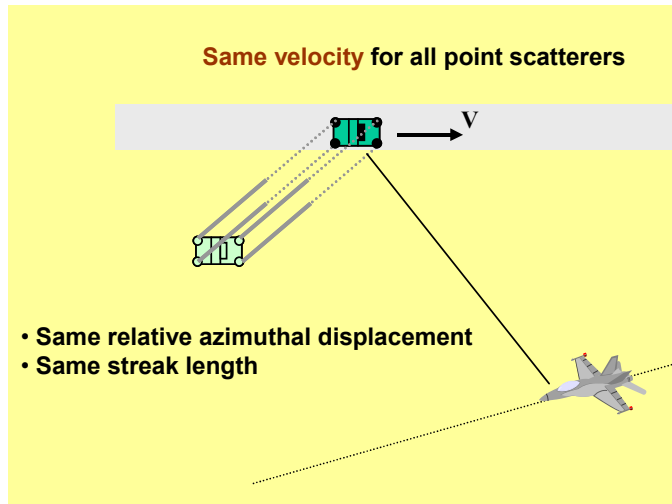
Predictable



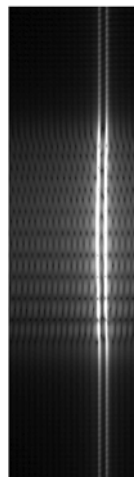
## **Veridian Will**

- Identify single aperture examples with significant effects of moving trees
- Apply the auto-focusing algorithm to known treed areas
- Extend and apply the prediction-based decomposition by using 1-D and 2-D prediction filters over the open areas identified by DFAD

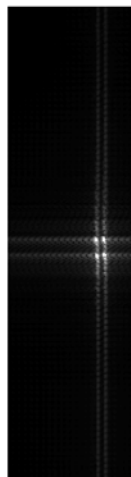
- **Problem:** In SAR, a moving target signature is spread and displaced in azimuth. The target detection and target (source) location estimation is very challenging due to reduced TCR and displaced signature, respectively. Focusing (compression) of the target signature (for ID) without the knowledge of the velocity over the aperture is poor.
- **Solution:** Use the knowledge of the road network on which the moving target is hypothesized to be.
- **Knowledge Source:**  
Road Network Information, SAR MAP



(a)

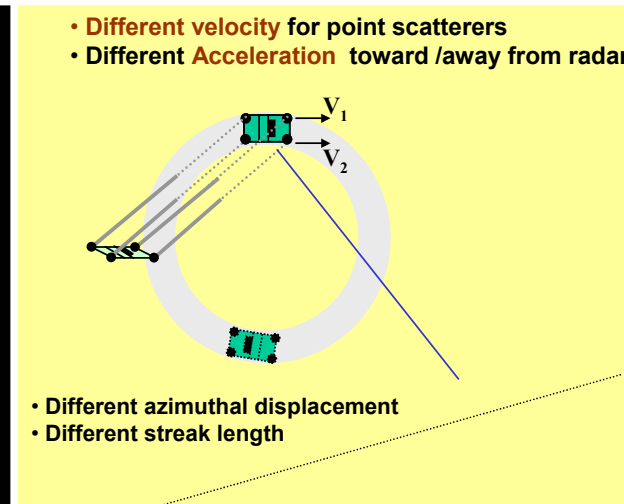


(b)

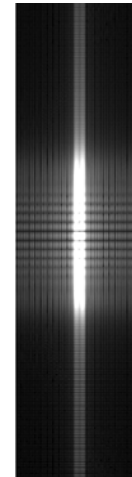


(c)

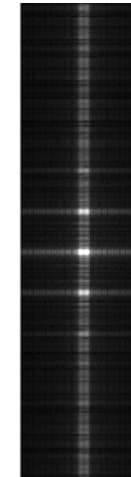
Figure 1. (a) Motion on a straight path. (b) simulation of a four point target. (c) refocusing by Shear Averaging Algorithm



(a)



(b)



(c)

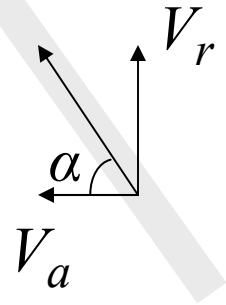
Figure 2. (a) Motion on a curved path, (b) simulation of a four point target. (c) refocusing by Shear Averaging Algorithm

### STRAIGHT ROADS

- Using region-maps (including roads)
  - Detect the streak (sharpness ratio)
  - Find the displacement of the streak in azimuth  $\Delta a$
  - From  $\Delta a = \frac{V_r}{V_p} \cdot R_0$ , calculate  $V_r$ , the range component of target velocity
  - Knowledge of the road and its curvature at any point, signifies the knowledge of the angle  $\alpha$ . Then,  $V_a = \frac{V_r}{\tan(\alpha)}$ .
  - The quadratic phase error due to target's motion is given by

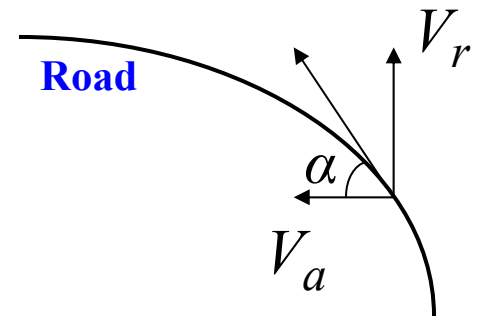
$$\varepsilon_{quad-phase} = -\frac{4\pi}{\lambda_0} (V_a t) \frac{(V_p t)}{R_0} + \frac{2\pi}{\lambda_0} a_r t^2$$

### Straight Road



### CURVED ROADS

- Using region-maps (including roads)
  - Detect the streak (sharpness ratio)
  - Find possible positions of the mover by intersecting the range extent of the streak with the known road.
  - For each candidate location, hypothesize on the constant speed and hence find the corresponding range and azimuth components of motion.
  - Remove linear phase error (displacement) and higher order phase errors (defocusing) due to the hypothesized speed.
  - Measure the degree of focusing at the candidate location.



### Veridian Will

- Identify wide aperture data with movers, and with available maps of the roads
- Detect movers hypothesized to move at a **constant speed** on the **known roads**
- Use the knowledge of the road to locate and focus the signatures
- Assess the performance



- **Problem:** Detection of moving targets.
  - **Solution:** Utilize previously collected single/multi-channel SAR/GMTI data for change detection
  - **Knowledge Source:** Previously collected SAR/GMTI
- 
- Veridian upgraded the 2-phase center DCS platform to a 3-phase center and recently made a collection with this upgraded system.
  - We intend to use this multi-channel data to extend the notion of change detection to GMTI.

## Reference Imagery

### Collected Imagery

	Single Channel	Multi-Channel
Single Channel	<ul style="list-style-type: none"> <li>• <b>Coherent CD</b> <ul style="list-style-type: none"> <li>○ Register the reference* and collected images</li> <li>○ Coherently subtract the two</li> </ul> </li> </ul> <p><i>*reference data must be free of movers</i></p>	
Multi-Channel	<ul style="list-style-type: none"> <li>• <b>Coherent CD</b> <ul style="list-style-type: none"> <li>○ Register and time-align the collected images</li> <li>○ Coherently subtract each collected image from the reference</li> <li>○ Determine the position and velocity of the mover from the phase information in CD products</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Non-Coherent CD</b> <ul style="list-style-type: none"> <li>○ Register and time-align the collected images. Repeat for reference imagery.</li> <li>○ Non-Coherently subtract each collected image from the non-coherent sum of all the reference imagery</li> </ul> </li> <li>• <b>Object-Level</b> <ul style="list-style-type: none"> <li>○ Apply STAP to both sets and threshold the statistics</li> <li>○ Compare the detections.</li> </ul> </li> </ul>

- KA-CFAR has relatively
  - low gain at either high TCR or low TCR
  - High gain at moderate TCR
- **Any inaccuracy** in the knowledge degrades KA-CFAR performance
- Significant quality improvement has been observed in RSA-3 image remapping by employing *a priori coarse* knowledge to mask low return areas.